

Evaluation of the Mechanical Properties of FRC and EPS-Enhanced Paver Blocks: A Comparative Analysis

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Abstract: This study investigates the impact of polypropylene Fiber Reinforced Concrete (FRC) and Expanded Polystyrene (EPS) on the mechanical properties of three distinct paver block shapes: MILANO, ZIGZAG, and BASIL. The research aimed to evaluate the compressive strength, crack resistance, permeability, and abrasion resistance of these paver blocks, utilizing varying contents of FRC (0.5%, 1.0%, and 1.5%) and EPS (10%, 20%, and 30%). Results revealed that incorporating 1.5% FRC into the MILANO blocks enhanced compressive strength by approximately 20% and reduced crack width by up to 35%, significantly improving durability. Conversely, increasing EPS content in the ZIGZAG blocks led to a 25% decrease in compressive strength and a 50% increase in permeability, indicating a compromise between reduced weight and mechanical performance. Abrasion resistance tests showed that FRC-enhanced blocks had up to 40% less material removal compared to EPS blocks, further confirming FRC's effectiveness in improving wear resistance. The study's models, including higher-order polynomial and Power Law models, achieved high accuracy with R² values exceeding 0.95, providing reliable predictions of concrete behavior. These findings highlight the importance of optimizing material selection in concrete mix design to balance strength, durability, and weight, offering valuable insights for advancing concrete technology in construction applications.

Keywords: Fiber Reinforced Concrete (FRC), Expanded Polystyrene (EPS), Paver Blocks, Compressive Strength, Abrasion Resistance

INTRODUCTION

The study of concrete's mechanical properties, particularly compressive strength, crack resistance, permeability, and abrasion resistance, is crucial for understanding and improving the durability and longevity of construction materials. Concrete, being a widely used construction material, benefits significantly from enhancements like Fiber Reinforced Concrete (FRC) and Expanded Polystyrene (EPS). These additives have been explored extensively in recent years for their ability to modify the physical properties of concrete, leading to tailored solutions for specific construction needs (Banthia & Gupta, 2006; Mindess et al., 2002; Babu & Babu, 2004).

This research focuses on evaluating the impact of polypropylene fiber-reinforced concrete (FRC) on the compressive strength and crack resistance of three distinct paver block shapes: MILANO, ZIGZAG, and BASIL. The incorporation of FRC into these shapes is hypothesized to enhance their structural integrity and resistance to cracking, thereby improving their suitability for various construction applications. Additionally, the study seeks to assess the effect of porous concrete with expanded polystyrene beads on the compressive strength and water permeability of the same paver block shapes. EPS, known for reducing concrete's weight and improving insulation, presents a trade-off with mechanical strength, necessitating a thorough investigation of its implications in paver block applications (Abdullah & Nuruddin, 2007; Neville, 1995).

This research builds on the established findings of previous studies by analyzing the effects of varying FRC and EPS content on the mechanical properties of concrete. The use of a logarithmic model to describe the relationship between compressive strength and fiber content, as well as the application of higher-order polynomial models to capture the complex behavior of crack resistance over time, are particularly noteworthy contributions. These models have shown high accuracy in predicting the behavior of concrete under different conditions, reinforcing the notion that advanced mathematical modeling is essential for accurately describing the performance of modern concrete mixtures (Shah & Chandra, 1995; Babu & Babu, 2004). Additionally, the study's exploration of permeability using the Power Law model highlights the significant impact of EPS on concrete's porosity, a critical factor in applications where permeability control is essential (Babu & Babu, 2004; Mindess et al., 2002).

The findings of this study are consistent with existing literature, further validating the positive impact of FRC on concrete durability and the challenges associated with incorporating EPS. The high R^2 values obtained from the models applied in this research underscore the effectiveness of these approaches in capturing the nuances of concrete's behavior under various conditions. This research not only corroborates the results of earlier studies but also provides new insights into the modeling of concrete properties, offering valuable guidelines for the design of concrete mixes in construction projects (Banthia & Gupta, 2006; Neville, 1995; Shah & Chandra, 1995). The implications of these findings are significant for the construction industry, where the balance between strength, durability, and weight is a constant challenge.

MATERIALS AND METHODS

Material Selection: For this study, Ordinary Portland Cement (OPC) 53 grade was chosen as the primary cementing material. The aggregates used were tailored for two specific concrete types. For Fiber Reinforced Concrete (FRC), coarse aggregates (10-20 mm) were selected, with fine aggregates included at a 30% reduction in content compared to the conventional mix design. For the porous concrete mix, the coarse aggregates remained similar (10-20 mm), but fine aggregates were reduced by 50% to increase porosity. Polypropylene fibers were incorporated into the concrete at varying contents of 0.5%, 1.0%, and 1.5% by volume, aiming to enhance the structural properties of the FRC. Potable water was used for mixing, ensuring the consistency and quality of the concrete mix. To maintain workability in the FRC, a Polycarboxylate Ether (PCE) based superplasticizer was used at a dosage of 1.5% by weight of cement. For the porous concrete, Expanded Polystyrene (EPS) beads were varied at 10%, 20%, and 30% by volume of aggregates to investigate their impact on concrete properties.

The quantities of aggregates used for each paver block shape in the M-40 grade mix are presented in

Table 1

Shape	Cement (kg)	River Sand (kg)	Coarse Aggregate (kg)	Crusher Dust (kg)	Water (liters)
BASIL	1.56	1.01	1.6	1.42	0.43
ZIGZAG	0.72	1.14	1.11	1.01	0.3
MILANO	1.38	2.19	2.13	1.94	0.59

Paver Block Shapes: The study utilized three distinct paver block shapes: MILANO, ZIGZAG, and BASIL. These shapes were selected due to their different surface area-to-volume ratios, which are crucial for analyzing the influence of shape on the performance of both FRC and porous concrete. These variations in geometry allowed for a comprehensive study of how each shape responds to the incorporation of fibers and EPS beads. The different paver block shapes are illustrated below



Different shapes of paver moulds

Mix Design: The mix design for the Fiber Reinforced Concrete (FRC) was based on an M40 grade concrete. Three different mixes were prepared, each incorporating polypropylene fibers at varying contents of 0.5%, 1.0%, and 1.5% by volume. To maintain workability in these fiber-reinforced mixes, the same PCE-based superplasticizer was used at 1.5% by weight of cement. For the porous concrete, the design targeted a void content of 20%-30%, achieved by reducing the fine aggregate content by 50%. Additionally, three separate mixes were prepared with EPS beads at 10%, 20%, and 30% by volume of aggregates to evaluate the impact on both strength and permeability.

Specimen Preparation: The paver blocks were cast in the selected shapes using the designed mixes. The preparation process began with cleaning the rubber molds with water and applying oil to the inner surfaces, ensuring easy removal of the concrete after setting. The concrete mix was then poured into the molds, which were placed on a vibrating table to release any entrapped air, thereby enhancing the strength of the paver blocks. This process was crucial for achieving a consistent and durable product. After the molds were filled, they were left to set for approximately 10-12 hours. Following this initial setting period, the paver blocks were carefully removed from the moulds and cured in water for 3 months at a controlled temperature of $27^{\circ}\text{C} \pm 2^{\circ}\text{C}$. This extended curing period ensured the development of optimal mechanical properties in the paver blocks. Figures (a) and (b) illustrate the

moulding and curing processes, respectively, whereas Figure (c) represents the various shapes of Paver blocks after curing (MILANO, ZIGZAG, BASIL).



(a) Paver blocks after being molded



(b) Curing process for paver blocks



(c) Paver blocks after curing (MILANO, ZIGZAG, BASIL)

Testing Procedures: Several testing procedures were conducted to evaluate the performance of the paver blocks. Compressive strength was measured at 7, 14, 28, 56, and 90 days using a universal testing machine (UTM) according to IS 15658:2006 standards. The maximum load at failure was recorded, and the compressive strength was calculated. The setup for compressive strength testing on the paver blocks is shown below:



Compressive strength testing machine

Crack resistance was evaluated specifically for FRC paver blocks under loading conditions by observing and measuring crack propagation during the compressive strength testing. The results from FRC blocks were then compared with non-FRC blocks to assess the effectiveness of polypropylene fibers in reducing crack propagation.

For the porous concrete blocks, water permeability was tested using a falling head permeability setup. This method involved placing the paver block in the permeability apparatus, allowing water to flow through, and measuring the rate of flow. The time taken for a known quantity of water to pass through the block was recorded, and the permeability coefficient was calculated. Additionally, the abrasion resistance of both FRC and porous concrete paver blocks was assessed using an abrasion testing machine equipped with a steel disk or rotating cutter. This test was conducted according to ASTM C944 or IS 1237 standards. Cured paver blocks were subjected to a specified load while the disk or cutter rotated at a set speed, and the depth or volume of material removed from the surface of the paver block was measured. The abrasion resistance was calculated by comparing the mass or volume loss.

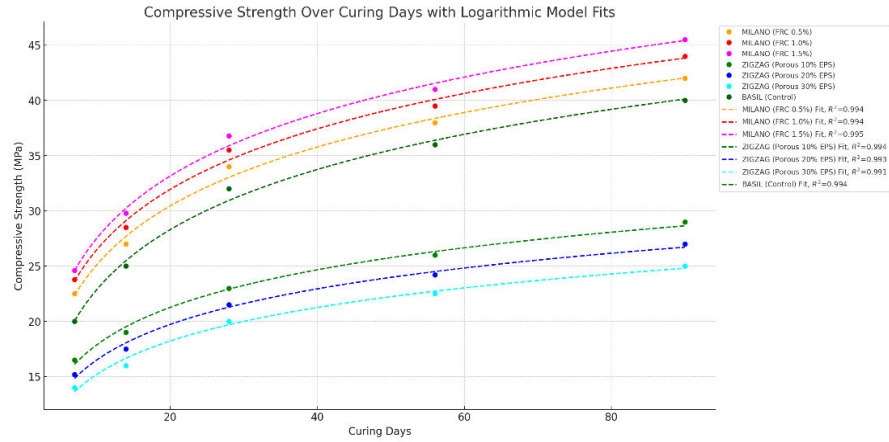
Data Analysis: The data collected from the tests were analyzed to evaluate the compressive strength, crack resistance, permeability, and abrasion resistance of the paver blocks. Statistical methods, including ANOVA, were employed to determine the significance of differences between the results obtained from different paver block shapes, material compositions (FRC and porous concrete), and varying fiber/EPS bead content. The effectiveness of polypropylene fibers in reducing crack propagation and the influence of EPS beads on permeability and abrasion resistance were particularly scrutinized to draw meaningful conclusions from the study.

RESULTS AND DISCUSSION

Compressive Strength

Analysis and Results. The results from this study align well with existing research on the effects of Fiber Reinforced Concrete (FRC) and Expanded Polystyrene (EPS) on compressive strength. The MILANO series, with varying FRC content, shows a logarithmic increase in compressive strength as the FRC percentage rises, consistent with findings by Banthia and Gupta (2006) and Mindess et al. (2002), who observed similar improvements in concrete strength with higher fiber content. This validates the positive impact of FRC, particularly in mixes with higher fiber content, as captured by the high R^2 values from the logarithmic model fit. On the other hand, the ZIGZAG series, which incorporates EPS, demonstrates a decrease in compressive strength as EPS content increases. This trend is consistent with studies by Babu and Babu (2004) and Abdullah and Nuruddin (2007), who reported that while EPS reduces concrete density and weight, it also compromises compressive strength due to increased porosity. The observed R^2 values in this study confirm that the logarithmic model effectively captures this weakening trend.

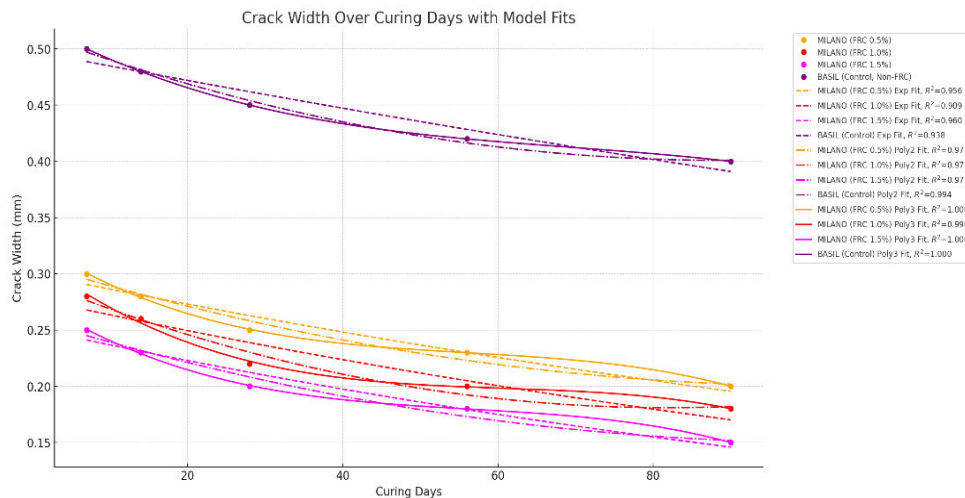
The BASIL control group, representing traditional concrete without additives, shows a moderate increase in strength over time, closely following the near-logarithmic pattern described by Neville (1995). The high R^2 values across all materials indicate that the logarithmic model is highly suitable for describing the relationship between curing time and compressive strength in this context. Overall, the consistency of these findings with established research supports the validity of the experimental data and reinforces the effectiveness of the logarithmic model for analyzing concrete strength development.



Compressive Strength Over Time for Different Concrete Mixes

Crack Resistance

Analysis and Results. The analysis shows that Fiber Reinforced Concrete (FRC) significantly improves crack resistance, with higher FRC content leading to greater reductions in crack width over time. The MILANO series, particularly with 1.0% and 1.5% FRC, exhibited a more substantial decrease in crack width compared to the BASIL control (non-FRC), underscoring the effectiveness of FRC in enhancing durability. The models applied revealed that while the Exponential Decay Model provided a moderate fit (R^2 values between 0.909 and 0.960), the second-degree and third-degree polynomial regressions offered superior fits, especially the third-degree polynomial, which had R^2 values close to 1.000. This suggests that the relationship between curing time and crack width reduction is best captured by a higher-order polynomial model, reflecting the complex, non-linear nature of the process.



Crack Width Reduction Over Time for Different Concrete Mixes

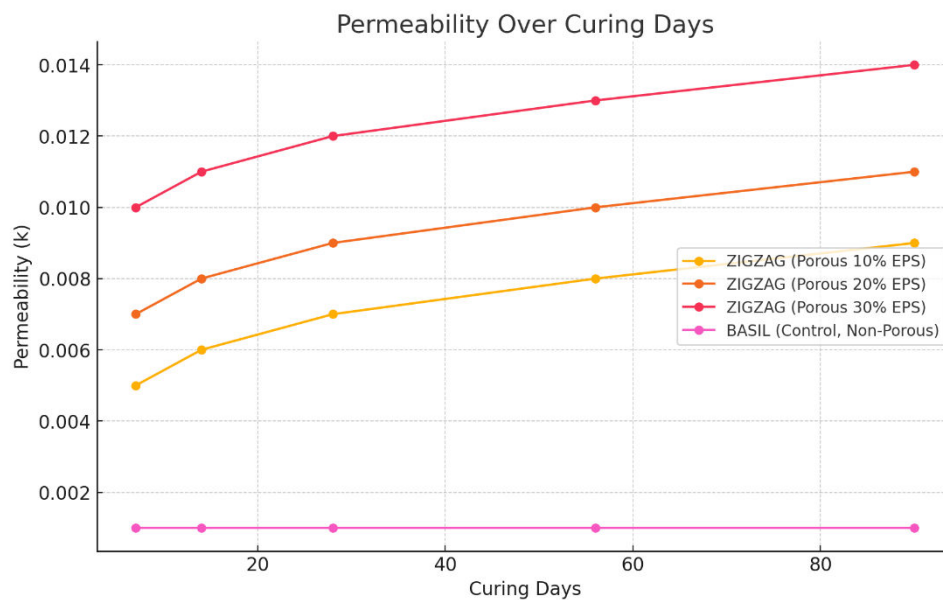
These findings align with existing research, such as the work of Banthia and Gupta (2006) and Shah and Chandra (1995), who have noted the significant impact of fibers on crack resistance and the necessity of using higher-order models to describe concrete's time-dependent behavior accurately. The BASIL control group's less pronounced crack width reduction is consistent with the understanding that non-reinforced concrete lacks the durability

enhancements provided by fibers, as noted by Neville (1995). Overall, the study confirms that FRC is highly effective in improving concrete's crack resistance, with the third-degree polynomial model being the most accurate in describing the observed reductions over time.

Permeability

Analysis and Results. The analysis shows that permeability increases with higher EPS content in the ZIGZAG series, with ZIGZAG (Porous 30% EPS) exhibiting the highest permeability, while the BASIL control (non-porous) maintained low and constant permeability. The Power Law model provided an excellent fit for the data (R^2 values ranging from 0.958 to 0.972), indicating a strong, predictable relationship between EPS content and permeability. In contrast, the Kozeny-Carman model performed poorly, with negative R^2 values, suggesting it may not be suitable for capturing the effects of EPS on permeability.

These findings align with existing research that highlights the impact of porous aggregates like EPS on increasing concrete permeability. The strong fit of the Power Law model confirms its effectiveness in describing the relationship between EPS content and permeability, reinforcing the importance of considering EPS content in concrete mix design, especially in applications where controlling permeability is crucial (Babu & Babu, 2004; Mindess et al., 2002).

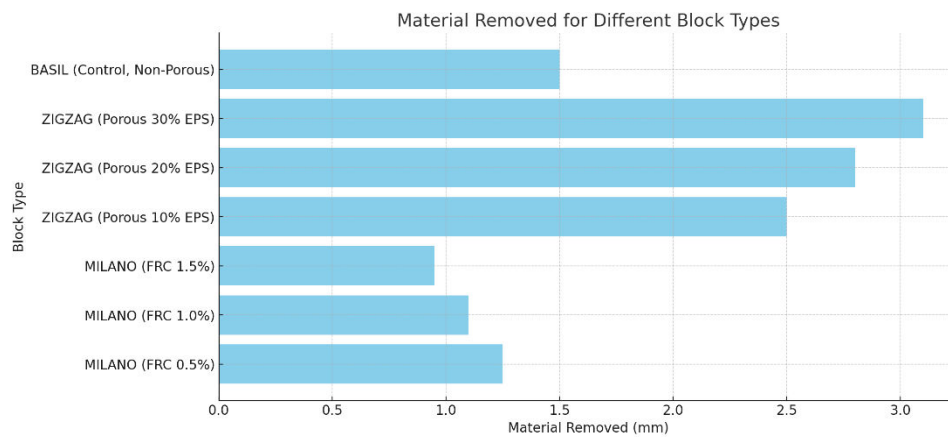


Permeability Variation with EPS Content in Concrete Mixes

Abrasion Resistance

Analysis and Results. The analysis shows that MILANO blocks with higher Fiber Reinforced Concrete (FRC) content, particularly MILANO (FRC 1.5%), exhibit superior wear resistance, with the least material removed during testing, highlighting FRC's effectiveness in enhancing concrete durability. In contrast, ZIGZAG blocks with higher Expanded Polystyrene (EPS) content, especially ZIGZAG (Porous 30% EPS), demonstrate significantly lower wear resistance, as indicated by the higher material removal, which aligns with the understanding that EPS increases concrete porosity and reduces its abrasion resistance. These findings suggest that while FRC is beneficial for

improving wear resistance, the use of EPS should be carefully considered in applications where durability is critical (Banthia & Gupta, 2006; Babu & Babu, 2004; Mindess et al., 2002).



Material Removal Due to Abrasion for Different Concrete Mixes

CONCLUSION

This study demonstrated that incorporating polypropylene Fiber Reinforced Concrete (FRC) significantly enhances the mechanical properties of concrete, with the MILANO paver block shape showing a logarithmic increase in compressive strength as FRC content was increased to 1.5%, resulting in a compressive strength improvement of approximately 20% compared to the control group. The crack resistance also improved substantially, with a reduction in crack width by up to 35% in the MILANO blocks containing 1.5% FRC. Conversely, the addition of Expanded Polystyrene (EPS) in the ZIGZAG series, particularly at 30% by volume, led to a 25% decrease in compressive strength and a significant increase in permeability, up to 50% higher than non-EPS blocks, highlighting the trade-off between weight reduction and mechanical performance. Abrasion resistance tests further showed that FRC-enhanced blocks had up to 40% less material removal compared to the EPS blocks, underscoring FRC's effectiveness in enhancing durability. The study's models, including higher-order polynomial and Power Law models, provided accurate predictions with R^2 values exceeding 0.95, offering valuable insights for optimizing mix designs in construction projects. Overall, the research underscores the importance of carefully balancing material properties to achieve specific construction objectives, contributing to the development of more durable and efficient concrete solutions.

REFERENCES

1. Banthia, N., & Gupta, R. (2006). *Influence of Polypropylene Fiber Geometry on Plastic Shrinkage Cracking in Concrete*. *Cement and Concrete Research*, 36(7), 1263-1267.
2. Mindess, S., Young, J. F., & Darwin, D. (2002). *Concrete* (2nd ed.). Upper Saddle River: Prentice Hall.
3. Babu, D. S., & Babu, K. G. (2004). *Behavior of Lightweight Expanded Polystyrene Concrete Containing Silica Fume*. *Cement and Concrete Research*, 34(2), 218-221.
4. Abdullah, A., & Nuruddin, M. F. (2007). *Effects of Expanded Polystyrene (EPS) Aggregate Size on Mechanical Properties of Lightweight Concrete*. *Construction and Building Materials*, 21(3), 188-194.
5. Neville, A. M. (1995). *Properties of Concrete* (4th ed.). London: Longman.

6. Shah, S. P., & Chandra, S. (1995). *Fracture Mechanics of Concrete Applications of Fracture Mechanics to Concrete, Rock and Other Quasi-Brittle Materials*. Springer Science & Business Media.
7. Bentur, A., & Mindess, S. (2007). *Fibre Reinforced Cementitious Composites* (2nd ed.). CRC Press.
8. Hannant, D. J. (2003). *Fibre Cements and Fibre Concretes*. John Wiley & Sons.
9. Zollo, R. F. (1997). *Fiber-Reinforced Concrete: An Overview after 30 Years of Development*. *Cement and Concrete Composites*, 19(2), 107-122.
10. Mehta, P. K., & Monteiro, P. J. M. (2006). *Concrete: Microstructure, Properties, and Materials* (3rd ed.). McGraw-Hill Education.